

LUMINANCES AND VISION RELATED TO DAYLIGHTING

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ABSTRACT

Daylighting has an excellent color rendering, as human eyes have been developed under the sun's rays, and it yields very proactive elements to human behavior.

In the field of luminance contrast, it has been noted that the probability of excessive contrast is lower when considering daylighting in relation to artificial lighting.

As a result, in activities which require more demanding visual accuracy, daylighting can offer more and better conditions for light and space variations considering the wide range of the field of vision.

This paper proposes a new approach to the methodology of calculating luminance balances considering the surface position in space and its relative weight in the final mean luminance value. This is based on ergonomic field of vision distribution, which confers major importance on what is in the solid angle analyzed by the cones area of the eye. The starting point when constructing numerical models of lighting comfort is the human eye's sensitivity to light.

Assessing interior architectural visual comfort conditions is the ultimate purpose of this work, along with the possibility of taking advantage of photography-related software programs that could be useful tools for architects and interior designers.

Avoiding uncomfortable visual situations is an environmentally efficient approach because the end effect of poor visual conditions is a higher demand for artificial

lighting, leading to energy consumption that could be saved with lighting conditions adapted to human comfort.

1. INTRODUCTION

Lighting comfort in an inhabitable space depends on the amount of light and how it is distributed. Naturally, users are more demanding when they find themselves in work spaces that require a high visual effort. Projects that aim to create an interior space with bright light yet without thinking about the balance of the light lead to uncomfortable situations, such as glare, for example.

Light sources are the main cause of unsatisfactory luminance balances [1]. For this reason, projects that use artificial lighting are so different to those that are resolved with natural daylight. Artificial lighting is more flexible when the distribution of lamps is planned (isolated light sources or smaller sources with lower intensity). However, daylighting depends on the windows (extensive light sources with high luminance), which always provide lateral light and often yield spaces with imbalanced lighting. The lighting levels tend to be quite high near the windows, and there is the risk of it being quite low in spots far from the windows. Furthermore, when the window appears within the user's field of vision, its high luminance is often the cause of glare.

This risk is particularly noticeable in climates characterized by having clear skies, such as the Mediterranean. The luminance of the sky associated with the window is quite high and proves to be more of a stumbling block to design solutions [2].

But design solutions are not the only problem. The evaluation methodologies themselves must be sensitive to the diversity of possible cases (artificial or daylight, cloudy or sunny skies). The classic formulation associated with glare offers coherent results when it evaluates cases of artificial lighting, but it is more difficult to apply in cases with daylighting, which is especially critical when dealing with very bright skies. In this last scenario, the calculations of glare would reveal that almost any window, regardless of its position with regard to the user, causes glare. However, experience tells us that this is not always so. [3] [4]

The purpose of this article is to provide further details and offer possible alternatives to calculation methods related to the luminance balance. The goal is for these methods to be more suitable to the particularities of daylighting, more specifically when evaluating cases with very luminous skies.

2. METHODOLOGY

The methodology used inspires an explanation with special reference to the particularities of the proposed calculation. Table 1 summarizes the stages in the evaluation process. Below the table, the particular features of each stage are explained in detail with a section for each of them.

TABLE 1: SUMMARY OF THE STAGES IN THE PROCESS

No.	STAGE	DESCRIPTION
1	Measuring instruments	Fisheye photography + Luminance meter
2	Luminance maps	HDR software + Calibration system
3	Image processing	Visual field + Solid angles calculation
4	Average luminance calculation of the visual field	Physiology of the eye + Comparative calculations with different models
5	Luminance balance of the visual field	Proposal for a calculation model

2.1 Measuring instruments

Two measuring instruments were used.

The first is a camera fitted with a circular fisheye lens (Sigma 4.5 mm F2.8). The result of the photographs taken with this lens is circular pictures inside the projection frame. The projection used is hemispheric and is known as the “equisolid angle projection”. Its unique feature is that it retains the proportions among the solid angles. The purpose of the photographs taken with this lens is to simulate the visual field of the human eye. However, vertically, the aperture angles of the lens are greater than those of the eye. As a result, the pictures are processed to eliminate the upper and lower parts from the evaluation, which should not be counted when simulating human vision. [5]

The second instrument is a device to measure luminances (Konica Minolta LS-110). Its acceptance angle is $1/3^\circ$ and its measurement range is from 0.01 to 999900 cd/m^2 . Both limits are enough to verify the measurements taken in this case study, as these margins were not exceeded in any case.

2.2 Luminance maps

By using the WebHDR software created by Axel Jacobs [6], digital photography can become a “map of false colors” which represents the luminances present in a space. This software enables us to choose between a logarithmic or linear scale of representation. The logarithmic scale is used since it more clearly represents the luminances in the case study. The scale offers ten possible luminance values (Fig. 1) which fit a predetermined range between 0 and 1000 cd/m^2 . This range is sufficient to represent the luminances existing in an interior space.

Only the luminance from the outdoors, present in the windows with a value higher than 1000 cd/m^2 , is outside the range. The software represents their value by associating them with the maximum value on the scale. In these cases, the value is replaced by the one provided by the luminance measuring tool.

Furthermore, a second reason justifies correcting the luminance of the windows. The WebHDR software graphically uses red and blue to warn that certain areas do not offer reliable luminance values, such as the areas that represent the luminance of the windows. When overexposed to light, their luminance value must be reconsidered. The luminance measuring tool solves this problem by providing the precise value, plus it also serves to calibrate the WebHDR software.

In parallel, and specifically for this study, the authors of this article developed their own software to read the luminosity of each pixel in a picture. The program reads the three RGB coordinates of each pixel, and adds them together to yield a luminosity value for a photograph which can vary between 0 and 765. After that, this luminosity value becomes a luminance value of surfaces through a normalization factor that is defined using the values of the luminance measuring tool. The purpose of this software is to provide a calculation tool that allows for a higher degree of detail.

2.3 Image processing

Image processing enables us to quantify the presence of each luminance within the field of vision. The first geometric operation is to eliminate two portions (an upper and a lower) from the circular image. The angular apertures of human vision define the limits of each portion. The lens used yields images that respect the “equisolid angle” geometric projection, whose main characteristic is that it retains the proportionality among solid angles, so we can directly measure the image. Two surfaces of the same size represent the same solid angle, regardless of their position in the image. Once this property is known, two calculation methods are put into practice.

The first consists of superimposing a template over the image yielded with WebHDR (Fig. 1), which is used to measure the area units of the same size (same solid angle). Each area is then associated with a given luminance and an angular deviation with regard to the centre of vision.

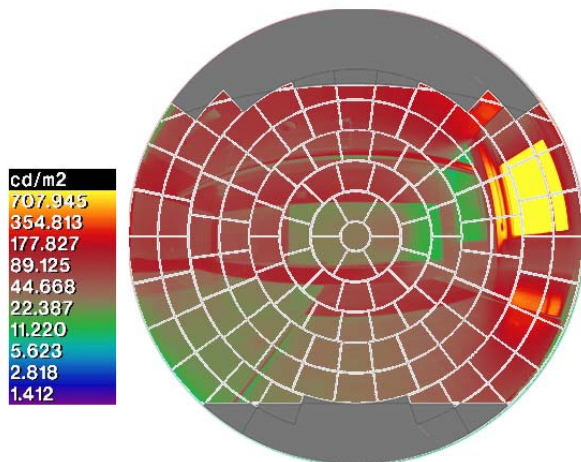


Figure 1: Subdivisions with the same solid angle superimposed on the WebHDR image.

The second method uses an original photograph and the software created by the authors of this article. The software enables the luminosity of each pixel (turned into luminance) to be associated with its position with regard to the centre of vision.

2.4 Average luminance calculation of the field of vision

The calculations of glare offer a comparison between the luminance of a light source and that of a visual background, which can be associated with the average luminance of the field of vision. The average luminance can be calculated using the following mathematical expression: [7]

$$(1) L_{med} = \frac{\sum L_i \times \omega_i \times f(\theta)}{\omega_0}$$

Where:

L_i is the luminance associated with a solid angle;

ω_i is the solid angle of each luminance;

ω_0 is the solid angle of the field of vision; and

$f(\theta)$ is the function that weighs the luminance by lowering its value according to the deviation angle with regard to the centre of vision.

$$(2) f(\theta) = \cos \alpha$$

The “weight” function $f(\theta)$ is usually the cosine function [8]. However, knowledge of the physiology of the eye gives rise to the proposal of other alternative functions in this article. The central region of the fovea has the highest density of cones [9]. At 10% eccentricity, the cone density is 100 times lower than in the center, and at 40° eccentricity, the density is 2000 times lower. The cone density justifies the fact that visual acuity is maximal in the center of the field of vision. An eccentricity of 10° implies a visual capacity ten times lower, while 60° eccentricity means that the visual capacity is 100 times lower. Bearing in mind these relations, the authors of the article propose four functions (alternatives to the cosine function) to weigh the prominence of luminances in the field of vision. Two functions are exponential (functions 3 and 4), while two functions stem from the Lorentz function, with two different width constants (function 5).

$$(3) f(\theta) = e^{-\frac{\alpha^2}{c^2}}$$

Where:

α is the deviation angle with regard to the centre of vision;
 $c = 5^\circ$.

$$(4) f(\theta) = e^{\frac{-\alpha^4}{c^4}}$$

Where:

α is the deviation angle with regard to the centre of vision;
 $c = 5^\circ$.

$$(5) f(\theta) = \frac{1}{1 + \left(\frac{\alpha}{c}\right)^2}$$

Where:

α is the deviation angle with regard to the centre of vision;
 $c = 5^\circ$ in the first case and $c = 10^\circ$ in the second.

Figure 2 compares all five functions. The four functions proposed differ considerably from the cosine function. They all accentuate the value of luminances present in the centre of vision and drastically lower the peripheral luminances. The one that does this the most mildly is the Lorentz function ($c=10^\circ$).

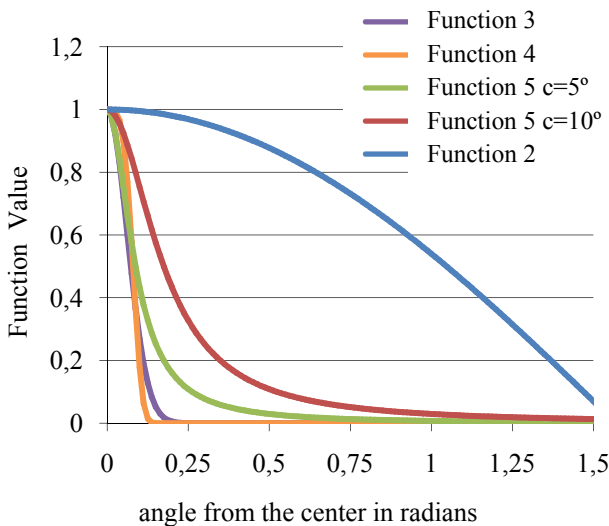


Figure 2: Comparative graph of the 5 weighing functions.

The study then continues by duplicating all the calculations, performing them with both the cosine function and the Lorentz function ($c=10^\circ$). This system

serves to evaluate whether the Lorentz function yields more useful results when evaluating average luminance, and later when evaluating the balance of luminances in the space with regard to an observer.

Finally, we must outline one last clarification. To calculate the average luminance, all of the luminances in the field of vision were considered, including the luminance of the source (window) which is regarded as likely to cause glare.

2.5 Luminance balance of the field of vision

The calculation of the luminance balance present in the field of vision uses the formulation which yields a glare index G and an index DG expressed as: [8] [10]

$$(6) G = 10 \log_{10} g$$

$$(7) DG = 2/3(G + 14)$$

Where:

$$(8) g = L_s^a \times \omega^b \times f(\theta) / L_b$$

With:

L_s being the value of the luminance source;
 ω being the value of the light source solid angle;
 a and b being coefficients; they are 1.8 and 0.8, respectively;
 $f(\theta)$ being the function that weighs the luminance by lowering its value according to the deviation angle with regard to the centre of vision; and
 L_b being the luminance value for the background of the light source.

The evaluation of the case studies below considers that the light source (L_s) is a window that provides light from the outdoors, while the background lighting is associated with the average luminance. As mentioned above, the calculation of $f(\theta)$ is duplicated, using both the cosine function and the Lorentz function.

3. CASE STUDY

The case studies test the methodology proposed to evaluate luminance balance. A classroom at the School of Architecture of the Polytechnic University of Catalonia in

Barcelona was the subject of the evaluation. The main feature of the classroom is that its façade is made of a modulation that alternates glass with opaque parts.

Two photographs, in which the only variation is the position of the window with the blinds open (more or less centered) enables us to test the sensitivity of the two formulations being compared (the cosine and Lorentz functions).

First, we took a photograph in which the blackboard is in the center of the vision. In the first version of this photograph (Fig. 3), just one window near the blackboard illuminates the scene. In the second version (Fig. 4), the open blind is far from the blackboard, on the periphery of the field of vision.



Figure 3: Blackboard 1



Figure 4: Blackboard 2

In the second case, the same photographs were taken in the same circumstances with regard to the open blind, but situating a computer screen in the center of vision on the table. The screen remains in both photographs with the same white background (luminance of 89 cd/m^2). Both photographs in which the screen appears in the middle are not included in this article because of its similarities to previous photographs.

4. RESULTS AND DISCUSSION

Table 2 summarizes the results obtained by applying the methodology to the case studies. In all cases, the luminance of the source (the window) is 3700 cd/m^2 . Its position is variable, either closer (42° and 54°) or further (72° and 78°) from the centre of the visual field (VF). What is more, the opening of the window leads to slight variations in all the luminances in the scene. The centered window raises the luminances near the blackboard, while the more lateral window boosts the peripheral luminance.

TABLE 2: SUMMARY OF THE RESULTS

VF	L_s	α	$f(\theta)$	L_{med}	G	DG
Blackboard 1	3700	42	Cos	188	33	31
			Lor	96	25	26
Blackboard 2	3700	72	Cos	102	32	31
			Lor	56	22	24
Screen 1	3700	54	Cos	177	32	31
			Lor	92	23	25
Screen 2	3700	78	Cos	90	31	30
			Lor	64	21	23

The results on this table correspond to the results obtained by processing the image using WebHDR and to the geometric screen corresponding to the “equisolid angle” projection. The results of the authors’ own software which evaluates the behavior pixel by pixel yields similar values. Therefore, this exercise enables us to validate the results obtained with both methods of calculation.

The discussion of the results addresses two issues (the value of the L_{med} and of the G index), which enables them to be distinguished even though they bear a close relationship to each other. We should recall that the new weighing via the Lorentz function changes the result of both concepts (L_{med} and the G index).

With regard to L_{med} , the results with the classic formulation (cosine) are more sensitive to the window position. Its values are higher since the luminance of the window has an important relative weight. In contrast, the results with the formulation proposed (Lorentz) are less sensitive to the window position. The resulting average luminance bears a close relationship to the luminances that predominate in the center of the field of vision. Therefore, its values are lower and less changing if the position of the open blind varies. It is acceptable to say that the new L_{med} attempts to be more faithful to the visual faculties of the eye, which sees more centered luminances more easily.

With regard to the G index, the results with the classic (cosine) formula are extremely high and largely exceed the maximum index of the classification (equal to 28), which describes situations with no comfort which are considered intolerable. In contrast, the experience at the time the photographs were taken and the results shown in the pictures enable us to state that the problem is not so dire and that the effect of the glare does not correspond to the results of the cosine formulation. The same evaluation methodology applied with the weight of the Lorentz function offers results which appear to be more in line with reality.

Another factor which deserves mention in relation to the G index is the differing sensitivity of both formulations (cosine and Lorentz) to the position of the light source. With the cosine function, the G index undergoes hardly any variation (one unit) when the open blind varies. However, as expressed in the reflection above, both experience and the photographs convey the sense of varying comfort, as the scenes in which the light source is more centered may be noticeably more uncomfortable. Once again, the same methodology, weighed using the Lorentz function, seems to more faithfully capture this sensation. The G index varies more when the position of the light source varies. In the case of the blackboard, the G index varies three units, while in the case of the screen it varies two units.

With regard to the DG index, the results and the conclusions are similar to those obtained with the G index.

5. CONCLUSION

This article starts with the existing methodologies to evaluate the balance of luminances and the risk of glare. The goal is to modify the function that weighs the importance of luminances in the field of vision (while remaining faithful to the human eye) in order to be able to apply the same methodology to scenes with daylighting (with more extensive and intense light sources than in the case of artificial lighting). The proposed weighing function (Lorentz) offers convincing results for two reasons. First, the glare indexes are lower, bringing them closer to the sensation noticed by users, and secondly, it is more sensitive to changes in the window position, showing that more centered light sources are more uncomfortable for users.

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